



U.S. DEPARTMENT OF ENERGY

**SMART**MOBILITY

Systems and Modeling for Accelerated Research in Transportation

# Smart Urban Signal Infrastructure and Control

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### Timeline

- Project start date: 10/1/2016
- Project end date: 9/30/2019
- Percent Complete: 15%

*[Deliverable complete for Quarter 2 in FY17]*

### Budget

- Total project funding:
  - DOE Share: \$810K for FY17-19
  - Contractor share: NA
- Fund received in FY16: 0
- Fund for FY17: 270K
  - ORNL Share: 200K
  - PNNL Share: 70K

### Partners

- Pacific Northwest National Laboratory
- National Renewable Energy Laboratory

### Barriers

- Infrastructure—Signal infrastructure in a connected environment
- Computational models, design and simulation methodologies
- Advances in vehicle, sensors, and communication technologies

**\*\*Based on VTO Multi-year program plan 2011-2015**

## Relevance/Objectives

- Overall objectives
  - Investigate the needs and roles of traffic signal systems in a connected environment focusing on **mobility**, **energy**, and **level of service**
  - Develop robust signal control schemes leveraging connected and automated vehicle technologies—*maximizing mobility with minimal energy*
- Objective this period (October 2016—March 2017)
  - Synthesis report on signal infrastructure and control methods
    - Identifying the needs to update the current infrastructure regarding CAV deployment
    - Transition of control schemes to automated environment
    - Exploration of the current efforts: field pilot studies, proposal of *Smart City* participants
- Impact
  - The synthesis study will serve as the starting point for updating the existing signal infrastructure and control elements as well as for the future development in a connected and automated environment

# Energy Efficient Mobility Systems (EEMS) Initiative: SMART Mobility Laboratory Consortium (SMLC)

- Task 4.0 of Urban Science Pillar
- Role & Potential of Signal Infrastructure in SMART
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  - E-mail: [azizh@ornl.gov](mailto:azizh@ornl.gov)



## Milestones and current status (Urban Science T 4.0)

Timeline	Milestone	Deliverables	Status
First Qt. FY17: (12/31/2016)	Identify questions and goals of synthesis study	NA	Complete
Second Qt. FY17: (03/31/2017)	Synthesis study on existing signal infrastructure and control schemes	(D4.1) A complete report including evidences and existing case studies from major cities (e.g., <i>smart city finalists</i> ) in the US	Complete
Third Qt. FY17: (06/30/2017)	Select and engage partners to explore priorities and strategic plans to accommodate CAVs in terms of smart-signal infrastructure investments	NA	On Track
Fourth Qt. FY17: (09/30/2017)	Assessment report on: future needs for signal infrastructure, challenges for cities towards transition, and role of CAV deployment	(D4.2) A white paper on the future challenges for urban signal infrastructure and control	On Track
FY18	Data Preparation, simulation tool selection (adaptation), scenario development through collaboration with other pillars	Scenarios relevant to the future SMART signal infrastructure and CAV deployment; Data ready for simulation studies	
FY19	Development and execution of signal control schemes accounting for the progress path of signal infrastructure and potential CAV market share	Algorithm implementation and quantification of energy minimization benefits along with travel delays and GHG emissions	



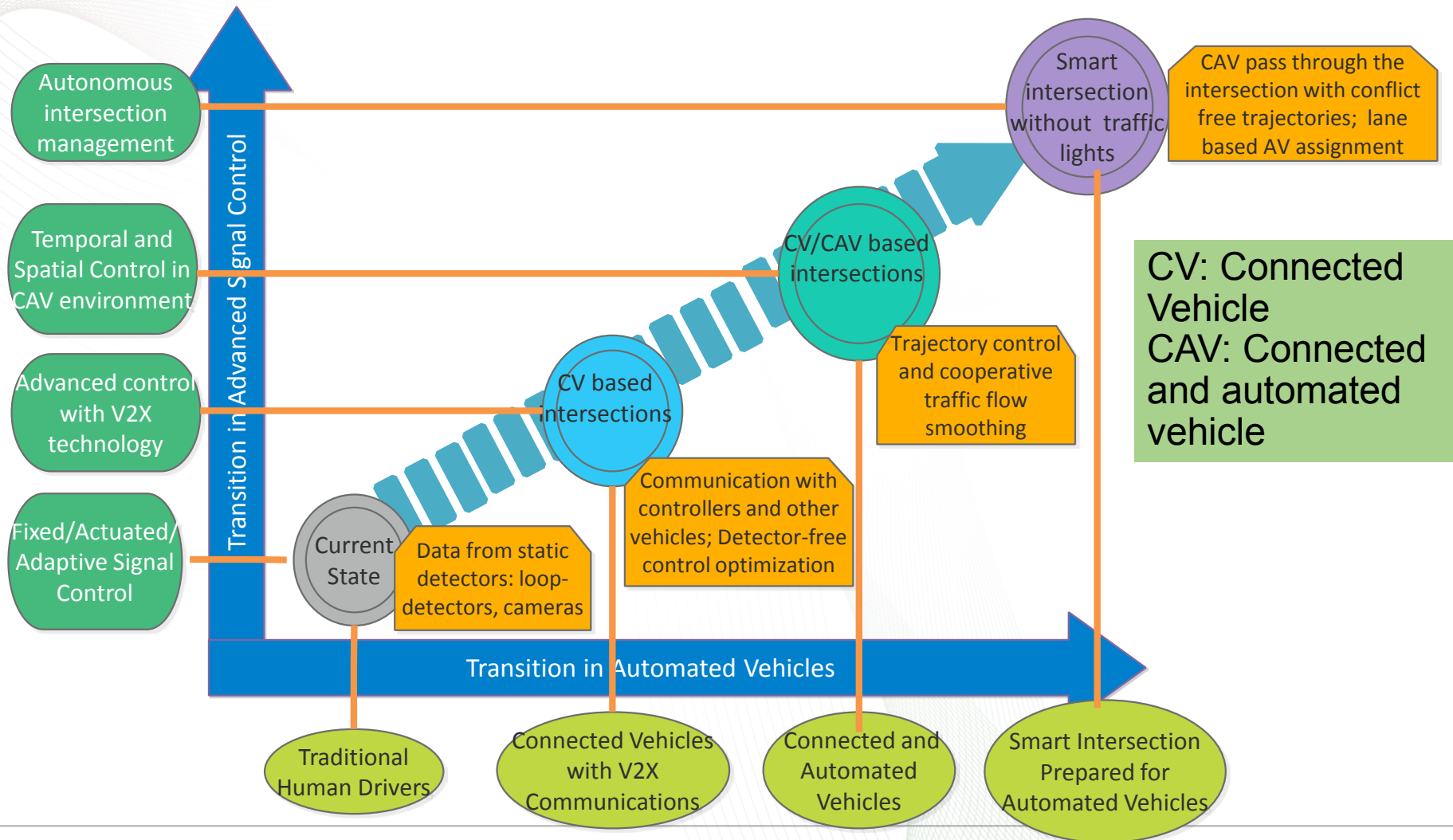
## Approach/Strategy (D 4.1: completed FY17 Q2)

- Key elements of the synthesis study
  - Existing signal infrastructure components and the its transition to the connected and automated intersection environment
  - Review of existing control schemes and future signal control applications that assume presence of Connected and Automated vehicles (CAVs)
  - Deployment cost of CAV based signal infrastructure and control system
- Signal control applications in Pilot studies and *Smart City* proposals
  - Connected vehicles deployment program: New York City, New York; Tampa, Florida; and rural Wyoming; total project funding: \$42 million
  - We have summarized the signal control applications proposed by the seven finalists of the *Smart City Challenge*
  - US DOT Connected Vehicle Pooled fund project
    - MMITSS (Multi Modal Intelligent Traffic Signal System)
    - Testbeds in Arizona and California

## Technical accomplishments [as of March 2017]

- D 4.1: Complete synthesis study on signal infrastructure and control systems
  - Will be distributed and published as ORNL technical report
- Acceptance in the ITE/CITE 2017 conference [Annual meeting of the Institute of Transportation Engineers]
  - Title: “Opportunities and Challenges in Traffic Signal Operations and Infrastructure Deployment in the Era of Connected and Automated Vehicles”

## Findings from synthesis study: Transition in Signal control and infrastructure





## Finding from synthesis study: CV/CAV based applications relevant to signal control

- Multi-modal signal control
  - Passenger cars, pedestrians, bicyclists, emergency vehicles, freight trucks
  - Priority based on temporal and spatial needs (freight priority near ports, pedestrian priority near schools or parks)
- Mobile accessible pedestrian signal system
  - Focused on pedestrian safety, cellphone based apps can talk to the Roadside units to request priority for visually impaired pedestrians
- Detector free signal control operations and retiming applications
- Autonomous intersection management without physical traffic lights

Finding from synthesis study: Anticipated cost for signal infrastructure deployment (in 2013 US dollars)

Component	Average cost
Signal controller upgrade for interfacing with DSRC RSU	\$3200
Direct DSRC and RSU installation cost per site	\$17600
To upgrade backhaul to a DSRC RSU site	\$3000-\$40000
Annual operations and maintenance cost for DSRC RSU site	\$3050
Integration of Existing Backhaul Equipment	\$3,000
Installation of New Backhaul	\$40,000

**Source: National Connected Vehicle Field Infrastructure Footprint Analysis**  
[http://ntl.bts.gov/lib/52000/52600/52602/FHWA-JPO-14-125\\_v2.pdf](http://ntl.bts.gov/lib/52000/52600/52602/FHWA-JPO-14-125_v2.pdf)

## Finding from synthesis study: Automated traffic signal performance management system (ATSPMS)

- CAV environment offers opportunity for ATSPMS
  - Real-time monitoring of traffic and signal performance metrics
  - Efficient re-timing
  - Data-driven applications
  - Utah implementation (<http://udottraffic.utah.gov/atspm/>)
- Automated performance observation system with High-Resolution Control Data (HRCD)
  - Can assist in traffic data collection
  - Origin-destination trip matrices estimation
  - Overall maintenance of the signal system

## Finding from synthesis study: Fault tolerant signal control system

- Potential risks
  - Power failure of Roadside Units, and traffic controllers under extreme events or undesired events/attacks
  - CAVs can be compromised by means of cyber attacks
  - System level bugs in the CAV deployment
- It is necessary to build a robust and fault tolerant system for safe and efficient operations of signal controllers
  - When signal controllers fail, CAVs can coordinate their movement through the intersections with non-conflicting trajectories for a short time
  - This approach requires a “critical mass” of CAVs to be present at the intersections during failure

## Finding from synthesis study: Synergistic applications

- Air quality monitoring system using CAVs-Signal network
  - CAVs can act as dynamic sensors and provide emissions data to a central air quality monitoring control center
- Travel time prediction and reliability assessment
  - The signal controllers and CAVs can create a network that can provide temporal and spatial travel time variance in a city
- Dynamic routing applications
  - Signal controller nodes can be used for dynamic routing under extreme event scenarios

## Finding from synthesis study: Challenges

- Traffic flow modeling with CAV interaction
  - What are the car-following rules in a mixed environment of human and self-driving cars?
- How does market adoption rate impact the performance of CAV-based signal control schemes?
  - What is the “critical mass” of CAVs to have an implementation with significant benefits in terms of travel time saving and reducing fuel consumption?
- What would be optimal investment plan for signal infrastructure from transportation agency perspective and how it could be aligned with private partners such as automobile and telecommunication industries?



## Future directions

- How quickly will signal infrastructure change in the next 10 to 20 years?
- How might signal infrastructure play a role in helping to curb or reduce energy usage in the age of increased connectivity and automation?
- What are the implications on congestion reduction and mobility benefits?
- Will transportation agencies be held responsible when an accident occurs with an automated vehicle behaving differently due to 'perhaps initially faulty' signal priority systems established?

## Response to Previous Year Reviewers' Comments

- **This project was not reviewed last year**

## Partners/Collaborators

- Pacific Northwest National Laboratory
  - Hong Wang
  - Role: Co-PI of the project
- National Renewable Energy Laboratory
  - Stanley Young
  - Role: PI for the *Urban Science* pillar and providing directions for the project goals and active tasks
- University of Tennessee, Knoxville
  - Two graduate students will be working during summer 2017

## Remaining challenges

- Development of the signal control schemes accounting for the mixed human and autonomous drivers
- Execution in a simulation platform that can handle large scale network of signalized intersections
- Integrating energy minimization objectives in signal control optimization framework

## Proposed future research

Work-State	Timeline	Milestone	Deliverables	Status
On-Going	FY17 3 <sup>rd</sup> Quarter	Select and engage partners to explore priorities and strategic plans	NA	On Track
	FY17 4 <sup>th</sup> Quarter	Assessment report on: future needs for signal infrastructure	(D4.2) A white paper on the future challenges	On Track
Proposed	FY18 2 <sup>nd</sup> quarter	Data Preparation, simulation tool selection based on scalability and adaptability	Prepare traffic models that account for mix of human drivers and CAVS	
	FY18 4 <sup>th</sup> Quarter	Scenario development through collaboration with other pillars and smart city partner	Scenarios relevant to the future SMART signal infrastructure and CAV deployment;	
Planned	FY19 2 <sup>nd</sup> Quarter	Development and execution and benefits for different market share of signal control schemes	Algorithm implementation in a simulation platform	
	FY19 4 <sup>th</sup> Quarter	Assessing energy impacts	Quantification of energy minimization benefits	

**Any proposed future work is subject to change based on funding levels**

### Relevance

- ❑ Explore the role of robust control infrastructure (signals and sensors) for heterogeneous traffic (mix of CAVs with human drivers) needed to leverage the ***energy gains of SMART Mobility***

### Approach (FY17)

- ❑ Develop a synthesis report on existing signal infrastructure, and Engage collaboration partners for case studies and data needs
- ❑ Identify the challenges and future needs in CAV environment focusing on—***maximizing mobility with minimal energy***

### Technical Accomplishments

- ❑ D 4.1: Complete synthesis study on signal infrastructure and control systems
- ❑ Acceptance in the ITE/CITE 2017 conference [Annual meeting of the Institute of Transportation Engineers]

### Proposed future research

- ❑ Data Preparation, simulation tool selection (adaptation), scenario development through collaboration with other pillars
- ❑ Development and execution of signal control schemes accounting for the progress path of signal infrastructure and potential CAV market share

***Any proposed future work is subject to change based on funding levels***



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